Neurourology and Urodynamics 23:184–189 (2004)

Stop Test or Pressure-Flow Study? Measuring Detrusor Contractility in Older Females

Thai Lian Tan,[1,3]* Margaret A. Bergmann,[2] Derek Griffiths,[1] and Neil M. Resnick[1]

[1]*Division of Geriatric Medicine, University of Pittsburgh, Pittsburgh, Pennsylvania*

[2]*Hebrew Rehabilitation Center for the Aged, Harvard University, Boston, Massachusetts*

[3]*Tan Tock Seng Hospital, Singapore*

Aims: Impaired detrusor contractility is common in older adults. One aspect, detrusor contraction strength during voiding, can be measured by the isovolumetric detrusor pressure attained if flow is interrupted mechanically (a stop test). Because interruption is awkward in practice, however, simple indices or nomograms based on measurements made during uninterrupted voiding are an appealing alternative. We investigated whether such methods, originally developed for males, might be applicable in female subjects, and attempted to identify a single best method. **Methods:** We compared stop-test isovolumetric pressures with estimates based on pressure-flow studies in a group of elderly women suffering from urge incontinence. Measurements were made pre- and post-treatment with placebo or oxybutynin, allowing investigation of test–retest reliability and responsiveness to small changes of contractility. **Results:** Existing methods of estimating detrusor contraction strength from pressure-flow studies, including the Schäfer contractility nomogram and the projected isovolumetric pressure PIP, greatly overestimate the isovolumetric pressure in these female patients. A simple modification provides a more reliable estimate, PIP_1, equal to $p_{det.Qmax} + Q_{max}$ (with pressure in cmH_2O and Q_{max} in ml/sec). Typically PIP_1 ranges from 30 to 75 cmH_2O in this population of elderly urge-incontinent women. PIP_1, however, is less responsive to a small change in contraction strength than the isovolumetric pressure measured by mechanical interruption. **Conclusions:** The parameter PIP_1 is simple to calculate from a standard pressure-flow study and may be useful for clinical assessment of detrusor contraction strength in older females. For research, however, a mechanical stop test still remains the most reliable and responsive method. The Schäfer contractility nomogram and related parameters such as DECO and BCI are not suitable for use in older women. *Neurourol. Urodynam. 23:184–189, 2004.* © 2004 Wiley-Liss, Inc.

Key words: bladder; geriatrics; urodynamics

INTRODUCTION

Among older people with lower urinary tract symptoms, impaired detrusor contractility plays an important pathological role [Resnick and Yalla, 1987; Resnick, 1988; Malone-Lee and Wahedna, 1993; Pagala et al., 2001]. Detrusor contractility has two aspects: the strength of the detrusor contraction; and whether the contraction is sustained [Griffiths and Van Mastrigt, 1985; Griffiths, 1991]. The contraction strength is not simply identical to the detrusor pressure, because when flow is occurring some of the strength of the contraction is used to generate the flow, and the pressure is lower than it would otherwise be. Because many different methods have been proposed to estimate the contraction strength the situation is quite confusing [Tan et al., 2002]. The isovolumetric pressure attained when flow is interrupted (the stop test) provides in theory a good estimate of contraction strength. In previous papers [Tan et al., 2002, 2003] we showed that, in older women, just as in men [Coolsaet, 1984; Sullivan et al., 1995], either mechanical interruption of voiding or continuous occlusion of the outlet during attempted voiding gave reliable results, while interruption of flow by voluntary contraction of the urethral sphincter was less reliable [Morita et al., 1984].

Mechanical interruption of flow, or continuous occlusion with a balloon catheter, interferes with voiding, is awkward to perform, may induce discomfort [Sullivan et al., 1995], and may even inhibit the patient from voiding altogether. In men, occlusion by a penile cuff may offer an acceptable alternative [Griffiths et al., 2002], but this is not possible in women. Therefore, other methods of estimating detrusor contraction strength from the values of detrusor pressure and flow rate

Grant sponsor: United States Public Health Service; Grant number: R01-DK49482; Grant sponsor: D. Pepper Older Americans Independence Center; Grant number: P01-AG08812; Grant sponsor: Health Manpower Development Program (Singapore) (to Dr. Tan).

*Correspondence to: Thai Lian Tan, Department of Geriatric Medicine, Tan Tock Seng Hospital, 11 Jalan Tan Tock Seng, Singapore 308433.

E-mail: thai_lian_tan@ttsh.com.sg

Received 9 July 2003; Accepted 8 December 2003

Published online in Wiley InterScience (www.interscience.wiley.com)

DOI 10.1002/nau.20020

measured during normal, uninterrupted voiding have been developed. Again there is a confusing variety of methods, but all are based on the bladder output relation (BOR), an inverse relation between pressure and flow that is analogous to Hill's equation for contracting muscle [Griffiths and Van Mastrigt, 1985; Griffiths, 1991]. If the slope and curvature of the BOR are known, the isovolumetric detrusor pressure can be estimated by extrapolating (projecting) the actual pressure back to the pressure axis (Fig. 1).

Schäfer [1995] described a method of this type. He simplified the BOR to a straight line with a fixed slope −K, independent of bladder volume (as in Fig. 1). The projected isovolumetric detrusor pressure (PIP) is then given by:

$$PIP = p_{det} + KQ \quad (1)$$

Schäfer took K to be 5 $cmH_2O/ml\ sec^{-1}$. In clinical practice, for a given void, PIP is evaluated at the point of maximum flow rate.

Schäfer suggested that values of PIP greater than 150 cmH_2O represented strong contractions (ST); values from 100 to 150 cmH_2O, normal contractions (N); values from 50 to 100 cmH_2O, weak contractions (W); and values below 50 cmH_2O, very weak contractions (VW). By drawing the corresponding BORs on a pressure-flow diagram (Fig. 1) he constructed a contractility nomogram that allows contraction strength to be classified in one of these four classes (later increased to 6). This nomogram, together with corresponding information on possible bladder outlet obstruction, provides in principle a convenient and useful visual clinical tool for classification of patients' voiding function.

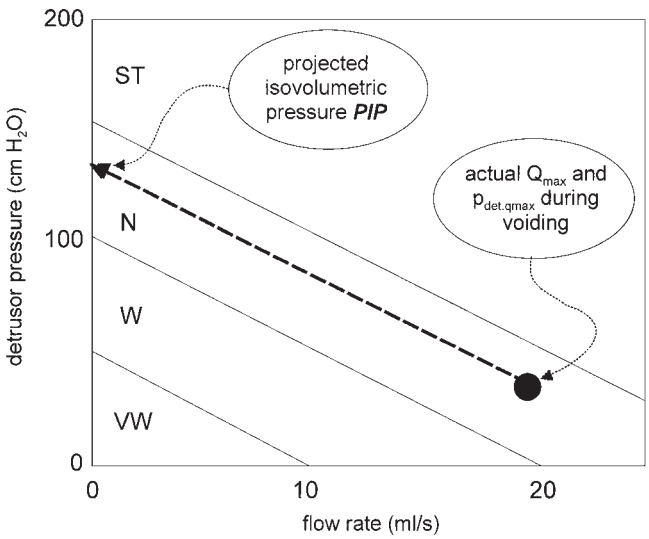

Fig. 1. Schäfer's contractility nomogram and the method of determining the projected isovolumetric detrusor pressure PIP. The maximum flow rate Q_{max} and corresponding detrusor pressure $p_{det.qmax}$ are plotted and projected back to the pressure axis as shown. In this case the value of PIP is about 130 cmH_2O, in the band labeled N, meaning that according to the nomogram this contraction has normal strength. Note: VW, very weak; W, weak, and S, strong.

Since 100 cmH_2O is a normal value for PIP, the ratio PIP/(100 cmH_2O) is a dimensionless coefficient for which values greater than 1 represent normal or ST, and values less than one, weaker contractions. Schäfer called this ratio detrusor coefficient (DECO). DECO (expressed as a percentage) is numerically equal to PIP (in cmH_2O). Later, Abrams described the bladder contractility index (BCI) [Abrams, 1999], which is essentially identical to DECO.

PIP (or DECO or BCI) is an appealing alternative for estimating contraction strength from standard pressure-flow measurements, without the technical and practical limitations of stop tests. A drawback is that it contains the constant K whose value has been chosen mainly on the basis of measurements in male patients. Clinical experience suggests that the projected isovolumetric pressure PIP is usually greater than the actual isovolumetric detrusor pressure, especially in female subjects.

The aim of this study was to investigate whether a simple index such as PIP, calculated from a standard pressure-flow study, can indeed take the place of a mechanical or continuous occlusion stop test; and if possible to justify or optimize the value of the constant K in this patient population, using as a criterion the consistency of the estimates of isovolumetric pressure obtained by the index and from stop tests.

METHODS

The study was based on a retrospective review of urodynamic data in a group of elderly females suffering from urge incontinence and enrolled in a trial of oxybutynin. The subjects were community-dwelling, independent, mobile, and cognitively intact. Detailed inclusion and exclusion criteria have been described in another study of the same data [Miller et al., 2002]. Subjects were randomized to either oxybutynin or placebo; the optimum dose was established by titration.

Comprehensive videourodynamic assessments were conducted at baseline and after 8 weeks of intervention. Testing included fluoroscopically monitored provocative medium-fill (30 ml/min) cystometry using room-temperature Cystografin with simultaneous monitoring of abdominal (rectal) pressure; isovolumetric testing; and upright or seated pressure-flow study. All methods, definitions, and units conformed to the then current recommendations of the International Continence Society [Abrams et al., 1988].

Measurements

The isovolumetric detrusor pressure was obtained for each subject via two types of stop test: a mechanical stop test and a continuous occlusion test. To perform these tests, a 12 French triple-lumen balloon catheter (Porgès AH5212) was introduced into the bladder through the urethra. The balloon, inflated to 5–10 ml, was positioned in the bladder near the bladder neck. The second lumen was used for bladder filling, and the third lumen for the measurement of the intravesical pressure. For the mechanical stop test, after bladder filling

and initiation of voiding in the supine position, flow was interrupted during mid-void by gently pulling the balloon catheter against the bladder neck. For the continuous occlusion test, again in the supine position, after refilling the bladder the outlet was occluded. The subjects were then asked to void (unknowingly) against the occlusion, which was maintained until the detrusor pressure began to decay significantly. Typically, the mechanical stop test and the continuous occlusion test give very similar results [Tan et al., 2002]. Because inhibition of the detrusor contraction is a potential artifact, the higher value was assumed to be the better representation of the potential detrusor contraction strength and is used in this paper as the reference value for comparison with other measurements.

After recatheterizing the bladder with a 6 French twin-lumen catheter and refilling, a pressure-flow study was recorded in the sitting position. Subjects were encouraged to void without abdominal straining, and abdominal pressure was monitored. As is usual in clinical practice, the maximum flow rate Q_{max} and the detrusor pressure at maximum flow $p_{det.Qmax}$ were used for further analysis.

Calculations

Using baseline data, we first compared the values of the original PIP ($K = 5\ cmH_2O/ml\ sec^{-1}$ in Eq. 1) with the reference values of isovolumetric detrusor pressure. Because there were substantial discrepancies (see below), indicating that the assumed value of K was not satisfactory, we made a direct estimate of the constant K for each subject, by rearranging Eq. 1 and substituting the reference isovolumetric pressure $p_{det.isv}$ and the pressure-flow readings at maximum flow in it:

$$K = (p_{det\cdot isv} - p_{det\cdot Qmax})/Q_{max} \qquad (2)$$

This yielded a distribution of values of K. Clearly there is no "correct" or "exact" value of K, but because the mean and the median bracketed a convenient round number (see Results: new parameter PIP_1), we chose this round number as the typical value of K for the baseline data of all subjects. Using this typical value in Eq. 1 we calculated a new projected isovolumetric pressure (PIP_1) at peak flow for each subject. For the baseline data, the values of PIP_1 were then compared with those of Schäfer's original PIP and the reference isovolumetric pressures.

In order to validate the conclusions, values of PIP_1 need to be compared with the reference values of isovolumetric pressure in a different data set. We used the follow-up (post-intervention) data set for this purpose.

Test–retest reliability was determined by comparing baseline and follow-up values of PIP_1 in the placebo group. Responsiveness to a small change in contractility was tested by comparing baseline and follow-up data in the group receiving oxybutynin, which causes a small reduction in isovolumetric detrusor pressure [Tan et al., 2003].

Statistics

SPSS (version 10.0) was used for the statistical analysis. The one-sample Kolmogorov–Smirnov test was used to test for normality and confirmed that the reference isovolumetric pressure had a non-normal distribution with positive skewness. Hence non-parametric tests were used for subsequent analyses: Spearman's Rho (ρ) to analyze the strength of correlation between variables; Wilcoxon's matched-pair signed-ranks test to determine whether two variables differed significantly. Linear regressions were constructed for related variables. Statistical significance was taken at two-tailed $P < 0.05$.

RESULTS

Baseline urodynamic data for 100 females were analyzed. The mean age of the subjects was 70.1 year (range 53–89). Eighty-two of the subjects (mean age 69.9, range 53–89) had follow-up data that were used for validation. Sixty two had received oxybutynin and 20 had received placebo.

$$\text{Original PIP}(K = 5\ cmH_2O/ml\ sec^{-1})$$

For the baseline data, the reference isovolumetric detrusor pressure given by the stop tests had a mean and standard deviation of $50 \pm 25\ cmH_2O$ (see Table I). The mean and

TABLE I. Comparison of the Reference Isovolumetric Pressure With the Estimates Given by PIP and PIP_1, for the Baseline Data Set (N = 100)

	Reference isovolumetric pressure (cmH_2O)	PIP ($K = 5\ cmH_2O/ml\ sec^{-1}$)	PIP_1 ($K = 1\ cmH_2O/ml\ sec^{-1}$)
Mean	50	133	49
Median	45	128	48
SD	25	45	17
5 and 95 percentiles	20/112	60/215	29/78
Mean difference (cmH_2O) from reference isovolumetric pressure (95% CI; Wilcoxon signed ranks test)	—	86 (76–96; $P < 0.05$)	0.2 (−5 to 5; $P = 0.98$)
Coefficient of correlation (Spearman's ρ) with reference isovolumetric pressure	—	0.21 ($P = 0.06$)	0.52 ($P < 0.01$)

standard deviation of PIP was 133 ± 45 cmH_2O. Thus PIP greatly overestimated the isovolumetric pressure, as shown in Figure 2. The mean difference between PIP and the reference isovolumetric pressure was 86 cmH_2O (95% CI 76–96). Moreover, there was only a weak correlation between PIP and the reference isovolumetric pressure (Spearman's $\rho = 0.21$, $P = 0.06$). A linear regression through the origin between PIP and the reerence isovolumetric pressure showed a gradient of 2.2 (Fig. 3a), greatly different from the slope (=1) of the line of equality.

New Parameter PIP_1

The inconsistency between PIP and the observed isovolumetric pressures prompted us to seek a similar but more representative parameter. For the baseline data, the mean and median values of K given by Eq. 1 were 1.19 and 0.84 $cmH_2O/ml\ sec^{-1}$, respectively. We therefore selected the value K = 1 $cmH_2O/ml\ sec^{-1}$ as typical of these subjects, and constructed a new parameter PIP_1, using Eq. 1 with this new value of K. The effect of using PIP_1 instead of PIP to calculate the projected isovolumetric pressure is illustrated in Figure 4. For the baseline data, PIP_1 was quite strongly and significantly correlated with the reference isovolumetric pressure ($\rho = 0.52$, $P < 0.01$), and it correctly estimated its value (mean difference = 0.2 cmH_2O [95% CI −5 to 5 cmH_2O]; Wilcoxon signed-ranks test, $P = 0.98$); see Figure 2. A linear regression through the origin showed a gradient of 0.85 between PIP_1 and the reference isovolumetric pressure (Fig. 3b), indicating approximate equality. Table I shows a numerical comparison of all three variables.

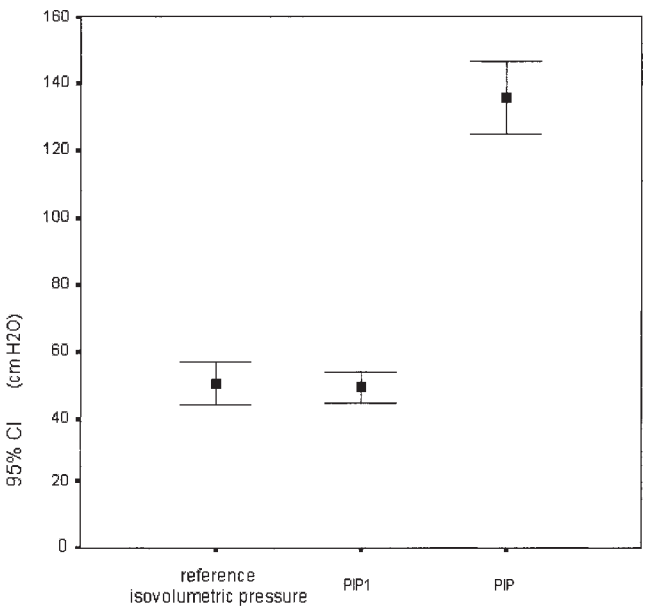

Fig. 2. Mean and 95% confidence intervals for the reference isovolumetric pressure $p_{det.isv}$ and the projected isovolumetric pressure as estimated by PIP_1 (K = 1 $cmH_2O/ml\ sec^{-1}$) and original PIP (K = 5 $cmH_2O/ml\ sec^{-1}$).

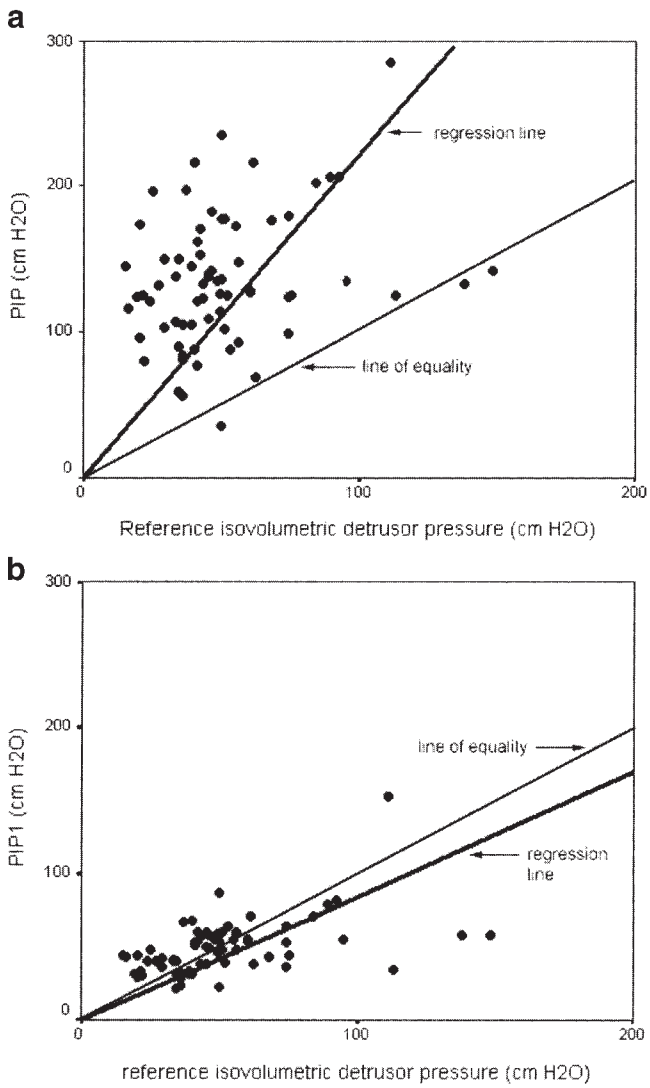

Fig. 3. a: Scatter plot of original PIP against the reference isovolumetric pressure, for baseline data; the regression line differs greatly from the line of equality. **b**: Similar plot for PIP_1; the linear regression line through the origin is close to the line of equality, showing that PIP_1 and the reference pressure are nearly equal on average; the scatter is less than in A.

Validation, Test–Retest Reliability, and Responsiveness to Change

The follow-up urodynamic data was used to validate the new parameter PIP_1. In this data set, the mean and standard deviation of the reference isovolumetric pressure were 48 ± 24 cmH_2O, with a median value of 42 cmH_2O. The mean and standard deviation of PIP_1 were 46 ± 14 cmH_2O and the median was 47 cmH_2O.

In the follow-up data set, Spearman's coefficient of correlation ρ between PIP_1 and the reference isovolumetric pressure was 0.37 ($P < 0.05$), and the mean difference between the

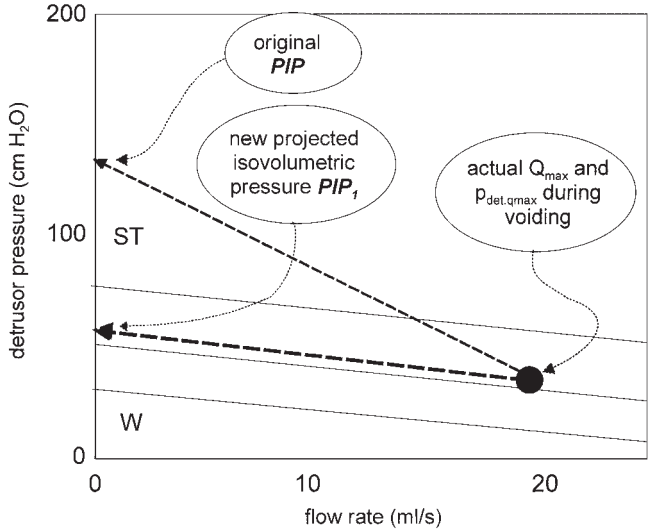

Fig. 4. To determine PIP_1 the point representing the pressure and flow rate measured during uninterrupted voiding is projected back to the axis with a line of slope -1 $cmH_2O/ml\ sec^{-1}$. (Note that the value of original PIP would be much larger.) For this void, the value of PIP_1 is about 60 cmH_2O, and the void falls in the band of typical values (unshaded). Values in the regions shaded gray would represent either stronger (ST) or weaker (W) contractions than those typical of the subjects in this group.

reference and estimated pressures was 3 cmH_2O (95% CI -3 to 9 cmH_2O; Wilcoxon signed ranks test $P = 0.96$). A linear regression through the origin between the estimated and reference isovolumetric pressures showed a gradient of 1.01.

As a measure of test–retest reliability, the changes in PIP_1 from baseline to follow-up were calculated for the subjects in the placebo group. The mean difference between baseline and follow-up values was 6 ± 5 cmH_2O (standard error; $n = 18$). Thus PIP_1 showed no significant systematic change from baseline to follow-up on placebo. The standard deviation of the difference (23 cmH_2O) indicates however that the random variations in PIP_1 are about ± 16 cmH_2O ($=23/\sqrt{2}$). Spearman's coefficient of correlation between baseline and follow-up values of PIP_1 was $\rho = 0.52$ ($P = 0.03$, $n = 18$).

Responsiveness to change was tested by looking for a decrease in PIP_1 after administration of oxybutynin, since the isovolumetric detrusor pressure as measured by continuous occlusion falls by approximately 4 cmH_2O on this medication [Tan et al., 2003]. In the oxybutynin group, the mean value of PIP_1 fell from 49 cmH_2O at baseline to 47 cmH_2O post-intervention, but this change was not statistically significant ($P = 0.16$).

Typical Values

In this group of older women with urge incontinence, 90% of the baseline values of PIP_1 fell between 29 and 78 cmH_2O. Thus contractions with PIP_1 smaller than about 30 cmH_2O might be considered unusually weak, and those with PIP_1 greater than about 75 cmH_2O unusually strong. The region between 30 and 75 cmH_2O would then be typical for this group, although it cannot be regarded as normal since the group itself is not normal. The resulting nomogram, similar to Schäfer's contractility nomogram for males, is shown in Figure 4.

DISCUSSION

In this paper, we have investigated whether a simple calculation based on a standard pressure-flow voiding study can replace a stop-test measurement of isovolumetric detrusor pressure as an estimate of detrusor contraction strength.

We have shown that some methods currently in use to deduce contraction strength from pressure-flow variables—the Schäfer nomogram, DECO, PIP, and BCI—are unsuitable for this older female population, because they greatly overestimate the isovolumetric detrusor pressure. However, a simple change of the assumed slope of the BOR, from $K = 5$ to $K = 1$ $cmH_2O/ml\ sec^{-1}$, overcomes this problem and provides a reasonable estimate of the isovolumetric pressure. The new contraction-strength parameter PIP_1 is obtained by adding together the detrusor pressure at peak flow and the maximum flow rate:

$$PIP1 = p_{det.Qmax} + Q_{max}$$

The test–retest reliability of PIP_1 is acceptable but not as good as that of a direct stop test [Tan et al., 2003], so that for example it is unable (in this group of subjects) to detect the effect of oxybutynin, which causes a small but significant decrease in isovolumetric detrusor pressure as measured by continuous occlusion. Thus, if a stop test is considered too cumbersome, PIP_1 may provide an adequate assessment of detrusor contraction strength. For research purposes however, a mechanical stop test may be preferable.

A limitation of this study is that it pertains only to older women with urge incontinence. In this group, the average values of PIP_1 and the isovolumetric pressure are close to 50 cmH_2O, and the typical range of PIP_1 is from approximately 30–75 cmH_2O. According to Schäfer's nomogram for males [Schäfer, 1995] all such contractions would be weak or VW, perhaps reflecting the fact that contraction strength decreases with age [Van Mastrigt, 1992] or that female bladders are less strong than male bladders. Certainly the reference values of isovolumetric pressure that we found in our female population are lower than those reported for males [Sullivan et al., 1995]. It is possible that the values are reduced because of inhibition of the detrusor contraction by the balloon, but one would expect this to happen in men also. Moreover, interruption of the stream per se does not inhibit the contraction [McIntosh et al., 2003]. In any case, the above range of values, and PIP_1 itself, may not be applicable to younger women, and certainly not to men. If measurement

of detrusor contraction strength is ever to take its proper place in the clinical and research arsenal, then measurements similar to those in this paper will be required for other patient groups, including normal individuals of various ages.

A further limitation is the assumption that the BOR is a straight line independent of bladder volume. This is almost certainly incorrect [Griffiths, 1991], although whether the error is important in clinical practice remains to be tested. It is possible that taking the curvature and volume dependence of the BOR into account would improve test–retest reliability and responsiveness to small changes of contraction strength.

Finally, we have confined our attention to the measurement of detrusor contraction strength. We have not addressed the second aspect of detrusor contractility: whether the contraction is adequately sustained. To assess global detrusor function, both aspects should be considered.

CONCLUSION

For elderly females with urge incontinence, the strength of the voiding detrusor contraction can be estimated from a standard pressure-flow study. However, the methods developed for men (the Schäfer contractility nomogram and the parameters DECO, PIP, and BCI) greatly overestimate the contraction strength. A new parameter PIP_1, given by $p_{det.Qmax} + Q_{max}$, where pressure is in cmH_2O and Q in ml/sec, provides a more reliable estimate. PIP_1 is easy to calculate and may be adequate for clinical routine. For research, however, a stop test or occlusion test still remains the most reliable and responsive method of determining detrusor contraction strength.

ACKNOWLEDGMENTS

We are grateful to Kathy Juliano for help with patient evaluation and recruitment. Dr. Griffiths provides urodynamics training in cooperation with Laborie Medical Technologies.

REFERENCES

Abrams P. 1999. Bladder outlet obstruction index, bladder contractility index, and bladder voiding efficiency: Three simple indices to define bladder voiding function. BJU Int 84:14–5.

Abrams P, Blaivas JG, Stanton SL, et al. 1988. The standardization of terminology of lower urinary tract function. Neurourol Urodynam 7:403–26.

Coolsaet B. 1984. Cystometry. In: Stanton SL, editor. Clinical gynecologic urology. St. Louis: The C.V. Mosby Company. pp 58–91.

Griffiths CJ, Rix D, Macdonald AM, et al. 2002. Noninvasive measurement of bladder pressure by controlled inflation of a penile cuff. J Urol 167: 1344–7.

Griffiths DJ. 1991. Assessment of detrusor contractility strength or contractility. Neurourol Urodynam 10:1–18.

Griffiths DJ, Van Mastrigt R. 1985. The routine assessment of detrusor contraction strength. Neurourol Urodyn 4:77–87.

Malone-Lee J, Wahedna I. 1993. Characterisation of detrusor contractile function in relation to old age. Br J Urol 72:873–80.

McIntosh SL, Griffiths CJ, Drinnan MJ, et al. 2003. Noninvasive measurement of bladder pressure. Does mechanical interruption of the urinary stream inhibit detrusor contraction? J Urol 169:1003–6.

Miller KL, DuBeau CE, Bergmann M, et al. 2002. Quest for a detrusor overactivity index. J Urol 187:578–85.

Morita M, Okamoto M, Ochi K, et al. 1984. Isometric detrusor pressure in the male patients: A comparison between voluntary urethral sphincter contraction and forced penile compression techniques. J Urol 134:1161–5.

Pagala MK, Tetsoti L, Nagpal D, et al. 2001. Aging effects on contractility of longitudinal and circular detrusor and trigone of rat bladder. J Urol 166:721–7.

Resnick NM. 1988. Voiding dysfunction in the elderly. In: Yalla SV, McGuire EJ, Elbadawi A, Blaivas JG, editors. Neurourology and urodynamics: Principles and practice. New York: Macmillan. pp 303–30.

Resnick NM, Yalla SV. 1987. Detrusor hyperactivity with impaired contractile function: An unrecognized but common cause of incontinence in elderly patients. JAMA 257:3076–81.

Schäfer W. 1995. Analysis of bladder outlet function with the linearized passive urethral resistance relation, linPURR, and a disease-specific approach for grading obstruction: From complex to simple. World J Urol 13:47–58.

Sullivan MP, DuBeau CE, Resnick NM. 1995. Continuous occlusion test to determine detrusor contractile performance. J Urol 154:1834–40.

Tan TL, Bergmann M, Griffiths D, et al. 2002. Detrusor contractility: Order out of chaos. Neurourol Urodynam 21:339.

Tan TL, Bergmann MA, Griffiths D, et al. 2003. Which stop test is best? Measuring detrusor contractility in older females. J Urol 169:1023–7.

Van Mastrigt R. 1992. Age dependence of urinary bladder contractility. Neurourol Urodyn 11:315–7.